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(54) **Topcoats for buffer-coated optical fiber.**

(57) Radiation-curable coating compositions adapted for application to buffer-coated optical fibers are disclosed. These are intended to apply an adherent topcoat having greater toughness and greater hardness than the buffer coating. The new compositions comprise: (1) from 25% to 70% of diethylenic-terminated polyurethane, which may include urea linkages, the polyurethane being based on a diisocyanate having an average molecular weight of from 400 to 5000; (2) from 5% to 40% of a diethylenically unsaturated ester of a diglycidyl ether of a bisphenol, said ether having a molecular weight up to about 1000; and (3) from 5% to 30% of liquid radiation-curable monoethylenically unsaturated monomer having a T_g above about 55°C., especially N-vinyl pyrrolidone. Ultraviolet cures using acrylates as the ethylenic group are preferred.

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TOPCOATS FOR BUFFER-COATED OPTICAL FIBER

DESCRIPTION

Technical Field

This invention relates to the coating of optical
5 fibers using radiation- curable coating compositions,
and more particularly to the provision of ultraviolet
curable topcoating compositions which are used to pro-
tect the primary or buffer coating which is applied to
protect the glass surface of the optical fibers. In
10 this description, the primary coating is also referred
to as a buffer coating because it intervenes between
the glass fiber and the topcoating. Since the buffer
coating is also referred to as a primary coating, the
topcoating may also be termed a secondary coating.

15 Background Art

Optical glass fibers are acquiring increasing
importance for communication purposes, but in order to
use the glass fibers it is necessary to protect the
glass surface from moisture and from abrasion. This
20 is done by coating the glass fiber immediately following
its formation. Solvent solution coatings and extrusions
have been applied, but these present problems which
have been solved to a considerable extent by the
employment of ultraviolet light-curable coating composi-
25 tions.

One problem presented by the use of coatings which
are adhered to the glass surface of the optical fiber
is caused by the difference in response to change in
temperature between the glass and the coating which
30 contributes to microbending of the fibers, especially
when very low temperatures are encountered. To minimize
this problem, coatings possessing a very low modulus
are selected to provide the primary coating, and ultra-
violet curable primary coating compositions have been
35 developed which possess this low modulus. These are
more fully described in certain commonly owned applica-

tions, namely: the application of Robert E. Ansel Serial No. 170,148 filed July 18, 1980 and the application of Robert E. Ansel, O. Ray Cutler and Elias P. Moscovis Serial No. 398,161 filed July 19, 1982(PCT/US/01094).

- 5 In order to provide the desired low modulus in the primary coatings, one must sacrifice desired hardness and toughness in the coating which contacts the glass. To increase the hardness and toughness of the exposed coating surface, it is desired to apply a secondary
10 coating on top of the primary coating, and the high speed application and cure of such secondary coatings and the resulting doubly coated optical fibers is the subject of this invention.

Disclosure of Invention

- 15 In accordance with this invention, a radiation-curable topcoat or secondary coating composition is provided in which: (1) from 25% to 70% of the coating composition is constituted by a diethylenic-terminated polyurethane, which may contain urea groups, said polyurethane
20 and being based on a diisocyanate having an average molecular weight of from 400 to 5000, preferably from 800 to 2500; (2) from 5% to 40% of the coating composition is constituted by a diethylenically unsaturated ester of a diglycidyl ether of a bisphenol, the ether having
25 a molecular weight up to about 1000, preferably below 400 (bisphenol A is preferred); and (3) from 5% to 30% of the coating composition is constituted by radiation-curable monoethylenically unsaturated liquid monomer having a T_g above about 55°C. The preferred ethylenic
30 group enabling ultraviolet cure is the acrylate group.

 This combination of radiation-curable components provides great physical toughness in combination with considerable hardness in an adherent coating, and the high T_g liquid monomer reduces the viscosity while
35 increasing the speed of radiation cure.

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T_g denotes the glass transition temperature of a homopolymer made from the monomer, and the high T_g monomers used herein are illustrated by dimethyl acrylamide, N-vinyl pyrrolidone, isobornyl acrylate and dicylopentenyl acrylate. N-vinyl pyrrolidone is especially preferred because it is far better at lowering viscosity while simultaneously increasing the speed of radiation cure.

While it is known that N-vinyl pyrrolidone, and to a lesser extent the other monomers listed, are capable of reducing the viscosity and increasing the cure speed of radiation curable coatings, it was not known that relatively large amounts of high T_g monomers would increase the hardness of the compositions under consideration while retaining the generally tough, moderate modulus character of the cured compositions. Thus, N-vinyl pyrrolidone, and to a lesser extent the other listed high T_g monomers, accomplish several commercially important objectives at the same time.

In this specification and the accompanying claims, all proportions are by weight, unless otherwise specified, and acrylates will be used as illustrative.

Referring more particularly to the diacrylate-terminated polyurethanes, these are formed by providing acrylate-functional terminal groups on a diisocyanate-terminated product having a molecular weight in the range of 400 to 5000, preferably 800 to 2500. While several production procedures are available, the diisocyanate-terminated product can be described as the reaction product of an organic diisocyanate with an aliphatic molecule having two isocyanate-reactive hydrogen atoms, as may be provided by OH, SH, or NH_3 groups. These diisocyanate-terminated reaction products include from 2 to 10 (preferably 2 to 4) urethane and/or urea groups.

The aliphatic groups may be a simple alkane diol, such as 1,6-hexane diol, but it is preferred that the

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aliphatic groups be selected from polyether, polyester and polyether-ester groups. Polyether groups are illustrated by tetramethylene glycol, polyester groups by the ester reaction product of two moles of ethylene glycol with one mole of adipic acid, and polyether-ester groups by the ester reaction product of two moles of diethylene glycol with one mole of adipic acid.

Appropriate diisocyanates may be aliphatic or aromatic, such as isophorone diisocyanate, 2,4-toluene diisocyanate and its isomers, and hexamethylene diisocyanate. Toluene diisocyanates are preferred, and this class of materials is well known in the art.

Diacrylate termination of the diisocyanates may be accomplished in various ways. Thus, one can form the higher molecular weight diisocyanates first, and then react with 2 molar proportions of hydroxy alkyl acrylate to thereby place one such unsaturated group on each available isocyanate group. These hydroxy alkyl acrylates may have from 2 to 6 carbon atoms in the alkyl group and are illustrated by hydroxy ethyl acrylate and by hydroxy propyl acrylate. Correspondingly, one can first react the hydroxy alkyl acrylate with one molar proportion of a low molecular weight diisocyanate and then react two molar proportions of the unsaturated monoisocyanate so-formed with one mole of a dihydroxy compound which provides the desired molecular weight. Both procedures are known to the art.

Urea groups may be incorporated into the polyurethane by reacting one mole of the previously described diisocyanates with one mole of hydroxy ethyl acrylate to provide an unsaturated urethane product containing a single unreacted isocyanate group. By then reacting two moles of this monoisocyanate with one mole of a diamine, such as butylene diamine, we obtain a polyurea polyurethane having two terminal acrylate groups. Urea-containing diacrylates are further illustrated in U. S.

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Pat. No. 4,097,439.

The diglycidyl ethers of a bisphenol which are employed preferably have a 1,2-epoxy equivalency of about 2.0, but anything in excess of about 1.4 is
5 useful herein. This merely means that the desired diglycidyl ethers are in admixture with monoglycidyl ethers which reduces the epoxy equivalency. These diglycidyl ethers, when of low molecular weight, can be used to form diacrylate (by addition to form hydroxy
10 acrylates). These, when used in combination with the diacrylate-terminated polyurethanes, provide the moderate modulus coatings which have good hardness and toughness, as previously described.

The term "bisphenol" denotes a pair of phenolic
15 groups linked together through an intervening divalent structure which is usually an alkylene group. When the phenolic OH groups on each of the phenol portions of the bisphenol are in the para position, and using 2,2-propylene as the intervening divalent structure,
20 the product is available in commerce where it is well known as bisphenol A.

Since ultraviolet light is preferred, acrylic unsaturation is best, but since the radiation character can vary, so can the specific character of the unsatura-
25 tion. Other useful ethylenic unsaturations are illustrated by methacrylic, itaconic, crotonic, allylic, vinylic, etc. These can be provided (using methacrylic unsaturation as illustrative) by reaction of isocyanate functionality with 2-hydroxyethyl methacrylate. Allylic
30 unsaturation may be introduced using allyl alcohol in place of hydroxyethyl acrylate. Vinylic unsaturation may be introduced using hydroxy butyl vinyl ether in place of hydroxyethyl acrylate.

Accordingly, while acrylate unsaturation has been
35 referred to previously as illustrative and preferred, other radiation curable monoethylenically unsaturated

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groups may be used in its place in the manner illustrated for methacrylic unsaturation.

The radiation which effects cure will vary with the photoinitiator used. Even visible light may be employed using appropriate photoinitiators. These are illustrated by camphor quinone and coumarin which are used together with a tertiary amine, such as triethyl amine. Diphenylbenzoylphosphine oxide is useful in and near the ultraviolet range.

When ultraviolet light is employed, the coating composition preferably contains a photoinitiator which is usually a ketonic photoinitiator, such as about 3% of diethoxy acetophenone. Other photoinitiators are also known, such as acetophenone, benzophenone, m-chloroacetophenone, propiophenone, thioxanthone, benzoin, benzil, anthraquinone, and the like. The photoinitiators may be used singly or in mixtures and are present in amounts up to about 10% of the coating composition. Various amines, such as diethyl amine, may also be present, but are not needed herein.

The radiation-curable coatings which are provided in accordance with this invention may be used for adhesives or for the coating of flexible floor tiles, but are very unique when applied as topcoats for buffer-coated optical fibers, as previously explained. Regardless of the use to which the coating compositions of this invention are put, and regardless of the radiation energy used to cure the same, they possess the same combination of superior hardness and toughness which allows them to serve as topcoats on optical fibers.

The coatings of this invention, when cured, possess a modulus which is generally in the range of 7000 to 14000kp/cm² (100000 to 200,000 psi) at room temperature. This is far too hard to serve as a coating which is directly in contact with the glass surface of the fibers. The buffer coatings which are used have a modulus measured at room tempera-

ture which is less than about 1050 kp/cm² (15000 psi).

Most radiation-cured coatings have a much higher modulus and are too brittle to be useful herein. When these brittle coatings are modified to make them less brittle, they possess little strength. The combination of hardness and toughness with moderate modulus provided herein adapts the instant coatings for specialized purposes, as previously described.

The invention is illustrated by a series of coating compositions formulated by simple mixing of the components tabulated below. The mixture is warmed to about 55°C. for 1 hour to dissolve all of the components.

TABLE 1

	Component	Ex. 1(control)	Ex. 2 (control)	Ex.3	Ex. 4
15	1	53.6	38.3	62.0	50.0
	2	17.3	29.0	14.2	24.6
	3	11.5	19.3	-	-
	4	4.6	3.4	-	-
	5	8.7	6.4	4.0	2.0
20	6	0.4	0.7	1.0	2.5
	7	0.01	0.01	0.01	0.01
	8	2.0	1.5	2.0	0.5
	9	-	0.01	-	-
	10	0.7	0.6	-	-
25	11	-	-	16.0	20.0

In the above tabulation, component 1 is an adduct of two moles of 2-hydroxyethyl acrylate with one mole of a diisocyanate-terminated polyurethane made by adducting a mixture of toluene diisocyanates (80% 2,4-isomer and 20% 2,6 isomer) with a polytetramethylene glycol formed by polymerizing tetrahydrofuran to form a polyether diol having a molecular weight of 600-800. The polyurethane formed by acrylating this diisocyanate has a molecular weight of about 1900 and includes an average of 5-6 urethane groups per molecule. The du Pont product Adiprene L-200 may be used.

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Component 2 is a diacrylate ester of a diglycidyl ether of bisphenol A, the ether having an average molecular weight of about 390. Shell product DRH 370 may be used as component 2.

- 5 Component 3 is tetraethylene glycol diacrylate.
 Component 4 is triethylene glycol diacrylate.
 Component 5 is trimethylol propane triacrylate.
 Component 6 is benzil dimethyl ketal which serves
 as a photoinitiator. Irgacure 651 of Ciba-Geigy may be
10 used as component 6.

 Component 7 is phenothiazine.

 Component 8 is benzophenone.

 Component 9 is 2-hydroxy-4-n-octoxybenzophenone.

 This compound serves as a light stabilizer.

- 15 Component 10 is diethyl amine.

 Component 11 is N-vinyl pyrrolidone

 Small amounts of auxiliary agents are useful in
 the above examples. One function served by such agents
 is to provide surface lubricity, a nonessential func-
20 tion. In all of the examples presented herein, surface
 lubricity is enhanced using silicone oils in small
 amounts. Examples 1 and 3 used 0.2% of Dow Corning
 fluid DC 57 and 0.6% of Dow Corning fluid DC 190. In
 examples 2 and 4, 0.07% of DC 57 was used with 0.13% of
25 DC 190. Example 4 also used 0.2% of N-beta-(N-vinyl-
 benzylamino) ethyl-gamma-aminopropyl trimethoxy silane.
 monohydrogen chloride. None of these additions is
 regarded to be important.

 The coating compositions in the Table 1 were used
30 as a topcoat on buffer-coated glass fiber. The optical
 glass fiber which was buffer coated had a diameter of
 about 125 micron and it was buffer-coated to a thickness
 of 125 micron using the low modulus buffer coating
 described in application of Ansel Serial No. 170,148
35 referred to previously. More particularly, the buffer
 coating was made by reacting 4 moles of 4,4'-methylene

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bis(cyclohexyl isocyanate) with 2 moles of polyoxypropylene glycol of molecular weight 1000 and then reacting with 2 moles of 2-hydroxyethyl acrylate and then with one mole of polyoxypropylene diamine of molecular weight 230 in the presence of 3.4 moles of N-vinyl pyrrolidone and 917 moles of phenoxyethyl acrylate. This mixture, with 3% by weight of diethoxy acetophenone, is ultraviolet cured on freshly formed optical fiber.

10 By applying the topcoats tabulated previously to the buffer-coated glass fiber in a thickness of 125 microns and then passing the wet-coated fiber through two tandemly arranged 250 mm (10 inch) medium pressure mercury vapor lamps (300 watts) at a velocity of 1.5 meters per second, the following results are obtained. The properties reported were measured on a free film having a thickness of about 75 microns.

TABLE 2

Property	Ex. 1	Ex. 2	Ex. 3	Ex. 4
20 Viscosity at application (cps. at 25°C.)	8,600	6,000	6,500	4,500
Cure speed (Ex. 1 is assigned a rating of 1)	1	1	1.2	1.2
Tensile strength kp/cm ² (psi)	203 (2900)	246 (3500)	301 (4300)	420 (6000)
% elongation	17	12	24	13
Modulus at 2.5 kp/cm ² (psi)	4690 (67,000)	7000 (100,000)	7000 (100,000)	9800 (140,000)
30 elongation				
Rupture strength cm kp/cm ²	56 (800)	56 (800)	140 (2000)	63 (900)
Hardness Shore D (initial)	55	56	63	68
35 Tukon hardness	4.0	5.8	6.9	10.0
T _g (°C.)	42	48	58	63

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Coefficient of
thermal expansion
(below T_g)

9

7

5.4

4.2

It will be appreciated from Table 1 that Examples
5 1 and 2 are presented herein as a control illustrating
prior practice.

As can be seen, while the results of the two
control experiments are satisfactory, Examples 3 and 4
are superior, and the result is surprising. This is
10 because the viscosities in Examples 3 and 4 are lower
than in Examples 1 and 2, respectively, and hence more
favorable. At the same time, the cure is faster and
the coefficient of thermal expansion below the glass
transition temperature is lower, so less strain is
15 placed on the glass fiber at low temperature.

C L A I M S

1. A radiation-curable coating composition adapted to be applied to buffer-coated optical fibers to apply an adherent topcoat having greater toughness and greater hardness than said buffer coating comprising:
5 (1) from 25% to 70% of the coating composition of diethylenic-terminated polyurethane which may include urea linkages, said polyurethane being based on a diisocyanate having an average molecular weight of from
10 400 to 5000; (2) from 5% to 40% of the coating composition of a diethylenically unsaturated ester of a diglycidyl ether of a bisphenol, said ether having a molecular weight up to about 1000, and (3) from 5% to
15 30% of the coating composition of liquid radiation curable monoethylenically unsaturated monomer having a T_g above about 55°C.

2. A coating composition as recited in claim 1 in which said diglycidyl ether is a diglycidyl ether of bisphenol A, said diglycidyl ether having an average
20 molecular weight less than 400.

3. A coating composition as recited in claim 1 in which said diethylenic-terminated polyurethane has an average molecular weight in the range of 800 to 2500.

4. A coating composition as recited in claim 1 in
25 which from 5% to 30% of the coating composition is constituted by liquid monomer selected from the group of dimethyl acrylamide, N-vinyl pyrrolidone, isobornyl acrylate, and dicylopentenyl acrylate.

5. A coating composition as recited in claim 4 in
30 which said liquid monomer consists essentially of N-vinyl pyrrolidone.

6. A coating composition as recited in claim 1 in which said diglycidyl ether of a bisphenol has a 1,2-epoxy equivalency of at least 1.4.

35 7. A coating composition as recited in claim 1 in which the polyurethanes which are diethylenic-terminated

contain an organic diisocyanate which is the reaction product of an organic diisocyanate with an aliphatic molecule having two isocyanate-reactive hydrogen atoms, said reaction product including from 2 to 10 urethane
5 and/or urea groups.

8. A coating composition as recited in claim 7 in which said aliphatic groups are selected from polyether, polyester and polyether-ester groups.

9. A coating composition as recited in claim 8 in
10 which said diethylenic-terminated polyurethane is obtained from an hydroxyalkyl acrylate in which the alkyl group contains from 2-6 carbon atoms.

10. A coating composition as recited in claim 9 in which said acrylate is hydroxyethyl acrylate.

15 11. A coating composition as recited in claim 8 in which said polyurethane includes urea groups.

12. An optical glass fiber prime coated with a coating having a room temperature modulus less than about 1050 kp/cm² (15.000 psi) overcoated with a radiation-
20 cured coating of the coating composition of anyone of claims 1 to 11.

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